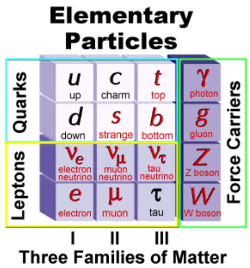
Physics 141.
Lecture 3.



1

Physics 141.
Lecture 3.

- Today's Topics:
  - Course Information:
    - Laboratories - software.
  - Chapter 1: Matter and Interactions
    - Building blocks of matter
    - The four fundamental interactions
    - Detecting interactions (part 1: observing motion)
  - A very quick review different types of motion (you should have seen these types of motion before in your high-school physics course):
    - Linear motion and variables.
    - Vectors.
    - Uniform circular motion.
    - Rotational motion and variables.
  - Chapter 1 continued
    - Detecting interactions (part 2: motion and forces)

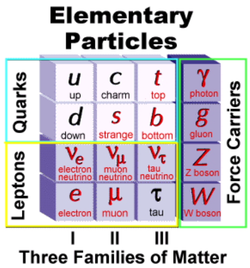
2

Physics 141 Laboratories.

- The Physics 141 laboratories will focus on experimental techniques and procedures.
- Schedule:
  - Exp. 1: 9/11 (B&L 407)
  - Exp. 2: 9/25 (B&L 407)
  - Exp. 3: 10/9 (B&L 407)
  - Exp. 4: 10/30 (B&L 407)
  - Exp. 5: 11/13 (Spurrier Gym) and 11/20 (B&L 407)
- Software used in the laboratory can be downloaded from the web (for both PC and Mac). The required password will be distributed via email.
- Data collected during the lab sessions can be analyzed in more detail afterwards.

3

The Building Block of Matter: The Standard Model Particles.



http://www2.slac.stanford.edu/vvc/theory/fundamental.html

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4

The Building Block of Matter: Grouped According to Spin.

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

http://particleadventure.org/particleadventure/frameless/chart.html

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5

The Building Block of Matter: Combining Quarks.

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

Mesons $q\bar{q}$
Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

http://particleadventure.org/particleadventure/frameless/chart.html

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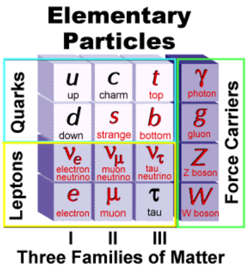
6

Types of Matter.



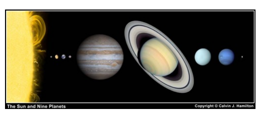
http://www2.slac.stanford.edu/vvc/theory/fundamental.html

- The elementary particles of the the standard model are point-like particles. They carry spin, mass, and charge (electric, color).
- Quarks are confined in hadrons (either two or three quarks) which are colorless.
- Protons and neutrons (hadrons) are the building blocks of nuclei.
- Nuclei and electrons are the building blocks of atoms.
- Atoms are the building blocks of molecules.

Types of Matter.

- The molecules form the molecular clouds from which solar systems, like are own, are created. Note: most of the molecules of life were first made in stars and dispersed in space when the stars die.

- Solar systems cluster to form galaxies.



Infra-red composite image of the Milky Way.
Source: NASA

The Four Fundamental Interactions.

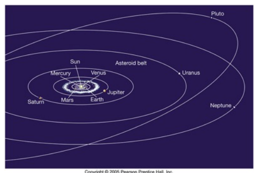
PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

http://particleadventure.org/particleadventure/frameless/chart.html

The Four Fundamental Interactions: The Gravitational Force.

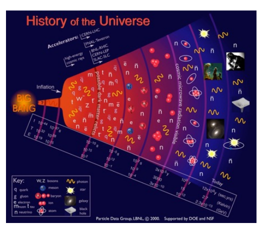
- The gravitational force is the weakest of the four fundamental forces.
- The gravitational force is always attractive.
- On large distances, the gravitational force dominates (e.g. the motion of our planets in our solar system can be described in terms of just the gravitational force).



10

The Four Fundamental Interactions: The Weak Force.

- The weak force is responsible for various exotic phenomena (e.g. parity violation).
- Interactions involving neutrinos usually occur via the weak force.
- Processes that occur via the weak force are usually characterized by long time scales (second, minutes, hours, ….). A good example is neutron decay.



http://particleadventure.org/particleadventure/frameless/chart.html

11

The Four Fundamental Interactions: The Electromagnetic Force.

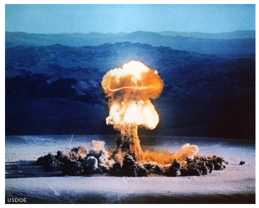
- The electromagnetic force is responsible for the formation of atoms.
- The electromagnetic force acts on electrically charged particles.
- The electromagnetic force can be attractive and repulsive.

http://www.downunderchase.com/

12

The Four Fundamental Interactions: The Strong Force.

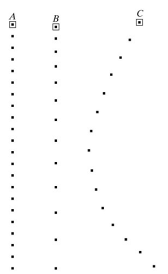
- The strong force is responsible for the stability of nuclei. Without the attractive strong force, the nuclei would fly apart as a result of the repulsive electric force.
- Differences in binding energies between different nuclei is responsible for phenomena such as nuclear fusion and fission.



13

Detecting Interactions.

- A non-zero force acting on an object will accelerate it:
  - Change its direction
  - Change its speed
- The change in the direction and/or speed provides us with information about the magnitude and the direction of the interaction.
- If we know the interaction we can determine the change in the direction and/or speed.
- To detect interactions we need to know how to describe motion and I will now quickly review important aspects of motion that you should have seen in high school.



14

Motion in one dimension: the equations of motion (non-relativistic).

- The position of an object along a straight line can be specified by a single parameter *x*.
- The velocity *v* and acceleration *a* of the objects are related to the time dependence of its position:

$$v(t) = \frac{dx}{dt} \qquad a(t) = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

- If the acceleration of the object is constant, its position and velocity are equal to

$$v(t) = v_0 + at$$

$$x(t) = x_0 + v_0 t + \frac{1}{2}at^2$$

15

Linear motion in one dimension.

Parameters define initial conditions!

$$x(t) \qquad x(t)=\int_{t_0}^{t} v(t')dt' \qquad x(t)=x_0+v_0t+\frac{1}{2}at^2$$

$$v(t)=\frac{dx}{dt} \qquad v(t)=\int_{t_0}^{t} a(t')dt' \qquad v(t)=v_0+at$$

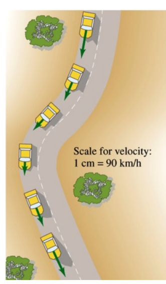
$$a(t)=\frac{dv}{dt}=\frac{d^2x}{dt^2} \qquad a(t) \qquad a(t)=a=\text{ constant}$$

The same for different observers!

16

Motion in two or three dimensions: vectors required.

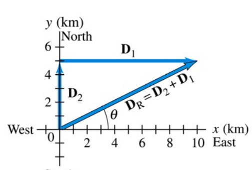
- In order to study motion in two or three dimensions, we need to introduce the concepts of vectors.
- Position, velocity, and acceleration in two- or three-dimensions are determined by not only specifying their magnitude, but also their direction.
- A parameter that has both a magnitude and a direction is called a **vector**.
- The relations between position, velocity, and acceleration are similar to those obtained for one-dimensional motion.



17

Using vectors to specify a displacement.

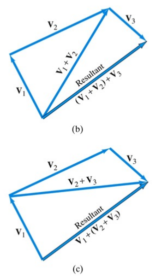
- The same displacement can be achieved in many different ways.
- Instead of specifying a heading and distance that takes you from the origin of your coordinate system to your destination, you could also indicate how many km North you need to travel and how many km East (vector addition).
- In either case you need to specify two numbers and this type of motion is called two dimensional motion.



18

Vector manipulations.

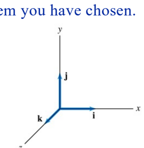
- Any complicated type of motion can be broken down into a series of small steps, each of which can be specified by a vector.
- I will make the assumption that you are familiar with the details about vector manipulations:
  - Vector addition
  - Vector subtraction
- You may want to review Section 1.4 of in the textbook (pg. 8 - 17).

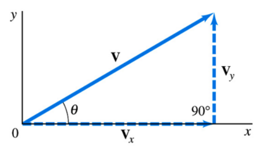


19

Vector components.

- Although we can manipulate vectors using various graphical techniques, in most cases the easiest approach is to decompose the vector into its components along the axes of the coordinate system you have chosen.





$$\sin\theta = \frac{V_y}{V}$$

$$\cos\theta = \frac{V_x}{V}$$

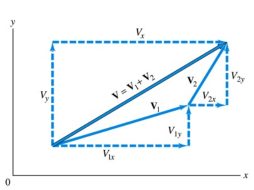
$$\tan\theta = \frac{V_y}{V_x}$$

$$V^2 = V_x^2 + V_y^2$$

20

Vector components.

- Using vector components, vector addition or subtraction becomes equivalent to adding or subtracting the components of the original vectors.
- The sum of the x and y components can be used to construct the sum vector.
- The difference of the x and y components can be used to reconstruct the difference vector.

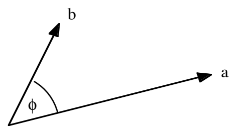


21

Other vector manipulations: the scalar product.

- The scalar product (or dot product) between two vectors is a scalar which is related to the magnitude of the vectors and the angle between them.
- It is defined as:

$$\vec{a} \bullet \vec{b} = |\vec{a}||\vec{b}|\cos\phi$$



- In terms of the components of **a** and **b**, the scalar product is equal to

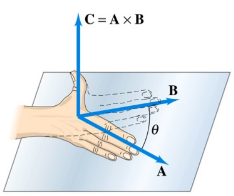
$$\vec{a} \bullet \vec{b} = a_x b_x + a_y b_y + a_z b_z$$

- Usually, you will use the component form to calculate the scalar product and then use the vector form to determine the angle between vectors **a** and **b**.

Other vector manipulations: the vector product.

- The vector product between two vectors is a vector whose magnitude is related to the magnitude of the vectors and the angle between them, and whose direction is perpendicular to the plane defined by the vectors.
- The vector product is defined as

$$|\vec{C}| = |\vec{A}||\vec{B}|\sin\theta$$



- Usually the vector product is calculated by using the components of the vectors **a** and **b**:

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \left(A_y B_z - A_z B_y\right)\hat{\mathbf{i}} + \left(A_z B_x - A_x B_z\right)\hat{\mathbf{j}} + \left(A_x B_y - A_y B_x\right)\hat{\mathbf{k}}$$

Motion in three dimensions: constant acceleration.

$$\vec{\mathbf{r}}(t) = \begin{pmatrix} x(t) \\ y(t) \\ z(t) \end{pmatrix} \quad \vec{\mathbf{v}}(t) = \begin{pmatrix} v_x(t) \\ v_y(t) \\ v_z(t) \end{pmatrix} \quad \vec{\mathbf{a}}(t) = \begin{pmatrix} a_x(t) \\ a_y(t) \\ a_z(t) \end{pmatrix} \quad \text{where}$$

$$x(t) = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \quad y(t) = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \quad z(t) = z_0 + v_{0z}t + \frac{1}{2}a_z t^2$$

$$v_x(t) = v_{0x} + a_x t \quad v_y(t) = v_{0y} + a_y t \quad v_z(t) = v_{0z} + a_z t$$

$$a_x(t) = a_x = \text{constant} \quad a_y(t) = a_y = \text{constant} \quad a_z(t) = a_z = \text{constant}$$

Note: A non-zero acceleration in one direction only affects motion in that direction.

A special case: projectile motion in two dimensions.

$$x(t) = x_0 + v_{0x}t \qquad y(t) = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

$$v_x(t) = v_{0x} = \text{ constant} \qquad v_y(t) = v_{0y} - gt$$

$$a_x(t) = 0 \qquad a_y(t) = -g = \text{ constant}$$

Note: The non-zero gravitational acceleration only affects motion in the vertical direction; not in the horizontal direction.

25

2 Minute 47 second intermission. Brought to you by the class of 2012.

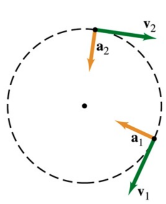
- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 2 minute 47 second intermission and listen to the Wolfs Song, created by these students after abusing my lecture recordings.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Go asleep, as long as you wake up in 2 minutes and 47 seconds.

According to these students, my exams are toxic.

26

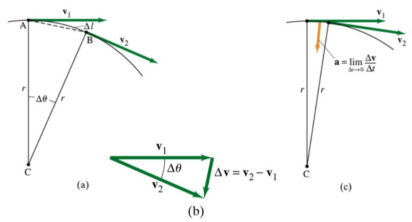
More complicated motion: uniform circular motion.

- Uniform circular motion of an object with period T can be described by the following equations:
  $x(t) = r_0 \cos(2\pi\, t/T)$
  $y(t) = r_0 \sin(2\pi\, t/T)$
- The motion of an object described by these equations is motion with constant (uniform) speed, $v_0 = 2\pi r_0/T$, along a circle of radius r_0.
- Important facts to remember:
  - The acceleration and the change in momentum vectors points towards the center of the circle.
  - The magnitude of the acceleration is v_0^2/r_0.



27

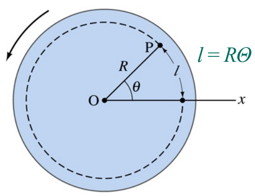
Uniform circular motion: the direction of the acceleration.



28

Circular/rotational motion: rotational variables.

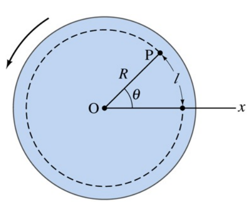
- Although we can use linear variables to describe circular motion it is often more convenient to use angular variables.
- The variables that are used to describe this type of motion are similar to those we use to describe linear motion:
  - **Angular position** Θ (rotation angle measured with respect to a reference axis - the x axis in this case). Units: rad.
  - **Angular velocity** $\omega = d\Theta/dt$. Units: rad/s.
  - **Angular acceleration** $\alpha = d\omega/dt$. Units: rad/s^2.



29

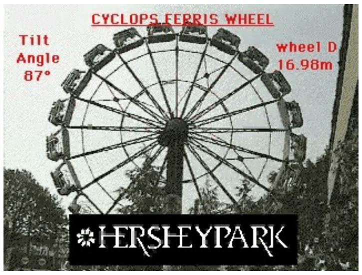
Circular/rotational motion: rotational variables.

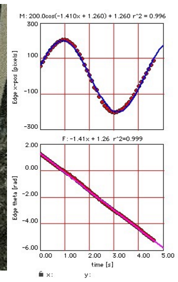
- Notes:
  - **The angular position is always specified in radians!!!!**
  - One radian is the angular displacement corresponding to a linear displacement $l = R$. Thus, one complete revolution (360°) corresponds to 2π radians.
  - Make sure you keep track of the sign of the angular position!!!!!
  - An increase in the angular position corresponds to a counter-clockwise rotation; a decrease corresponds to a clockwise rotation.



30

Complex motion in Cartesian coordinates is simple motion in rotational coordinates.





Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 03, Page 31

31

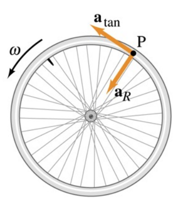
Circular/rotational motion: constant angular acceleration.

- If the object experiences a constant angular acceleration, then we can describe its rotational motion with the following equations of motion:

$$\omega(t) = \omega_0 + \alpha t$$

$$\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

- These equations are very similar to the equations of motion for linear motion.



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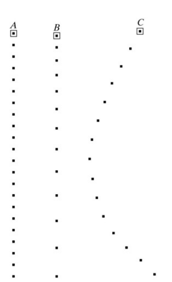
32

Detecting Interactions.

- A non-zero force acting on an object will accelerate it:
  - Change its direction
  - Change its speed
- The change in the direction and/or speed provides us with information about the magnitude and the direction of the interaction.
- If we know the interaction we can determine the change in the direction and/or speed.



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33

Detecting Interactions: Newton's First Law of Motion.

- Newton's first law of motion provides us with important information about the relation between the change in velocity (magnitude and/or direction) and the interaction:

  An object moves in a straight line and at constant speed except to the extent that it interacts with other objects.

- When different observers observe the motion of the same object, they will in general observe different velocities. If nature is beautiful, the laws of physics should be the same for these observers (and thus independent of velocity). This principle is **the principle of relativity**:

  Physical laws work in the same way for observers in uniform motion as for observers at rest.

34

Quantifying the extent of an interaction.

- The effect of an interaction will depend on both the velocity and the mass of the observed object:
  - It is easier to change the velocity of an object when it is moving slow compared to when it is moving fast.
  - It is easier to change the velocity of a light object compared to what is required for a massive object moving with the same velocity.
- It is observed that the change in the **linear momentum**

$$\vec{p} = \frac{m\vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

is proportional to the "amount" of the interaction.

35

Quantifying the extent of an interaction.

- For velocities small compared to the speed of light (c) our definition of the linear momentum approaches the more familiar definition you should have seen in your high-school physics course:

$$\vec{p} = \frac{m\vec{v}}{\sqrt{1 - \frac{v^2}{c^2}}} \approx m\vec{v} \text{ (if } v \ll c\text{)}$$

36

Quantifying the extent of an interaction.

- The change in the linear momentum of an object is proportional to the strength of the interaction and to the duration of the interaction. This principle is known as the **momentum principle**:

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- This equation allows us to calculate the time-dependence of the linear momentum if we know the initial value and the time/position dependence of the interaction.

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37

Quantifying the extent of an interaction.

- If we do not know the interaction, but we measure the change in the linear momentum we can determine extent of the interaction:

$$\vec{F}_{net} = \frac{d\vec{p}}{dt}$$

- In the non-relativistic limit this relation becomes

$$\vec{F}_{net} = \frac{d\vec{p}}{dt} \approx m\frac{d\vec{v}}{dt} = m\vec{a}$$

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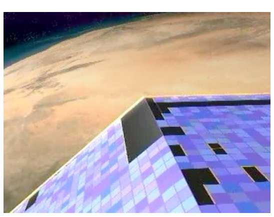
38

That's all for today! Next: Chapter 2.



The GRACE mission: measuring the Earth's gravitational field.
http://www.csr.utexas.edu/grace/

Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 03, Page 39

39